THE RESPONSE OF FLEXIBLE PAVEMENT ROADS TO LOADING FREQUENCY

Hüseyin Karadağ[1], **Seyhan Firat**[2]
[1] *Ministry of Family and Social Services, Turkey*
[2] *Gazi University Faculty of Technology, Turkey*

Abstract

Traffic load is one of the main factors that cause permanent deformation in the pavement, which is an important factor specifying road life and serviceability related to traffic safety. In addition to truck axle load level, deformation level in road pavement depends on superstructure materials, subgrade conditions, climate, groundwater conditions, number of load repetitions, and loading frequency. Loading frequency affects both the deformation level in pavement layers and the stress state. In this study, the effect of loading speed (loading frequency) was evaluated by carrying out a finite element analysis of certain flexible road pavement cross-sections under 400 kPa pressure. A triangular load pulse with 400 kPa was loaded on pavement cross-sections with different loading speeds. The analyzed cross-section of flexible road pavement consists of asphalt concrete layer, unbound base, and subbase layers. Subgrade material is the clay layer. For dynamic analyses of road pavement under the repetitive load of different loading speeds, 2D axial symmetric analyses were performed. The Hardening Soil Model with Small Strain Stiffness (HSsmall) soil model was used for modeling unbound granular layers and subgrade soil. Asphalt concrete was modeled with the Mohr-Coulomb material model. The tire contact area was assumed as a square area within 300 mm side length. Loading pulse durations were calculated for different loading speeds. The analyses show that the total vertical deformation for the analyzed section has a minimum value of 90 km/h loading Speed (6.94 Hz). As the loading speed increases or decreases, the total vertical deformation of the cross-section on either side of this point increases. The deformation graph has two local maximum points because of the resonance of the pavement system. These results are consistent with previous studies. Results show that controlling the loading speed will lengthen the road serviceability life by reducing the deformation.

Keywords: flexible pavement, loading frequency, FE analysis, deformation, dynamic analysis

1 Introduction

The permanent deformation of pavement is one of the main problems affecting road serviceability life and maintenance periods. Many factors affect the road pavement's permanent deformation. There are many studies about these factors in the literature, like axle load level, temperature, subgrade strength conditions, climate conditions, groundwater level, unbound materials and asphalt concrete strength properties, etc. However, there are limited studies on the loading speed of cyclic loading's effect on the permanent deformation of pavement. This study focuses on the effect of loading speed on the permanent deformation response of road pavements.

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The loading speed effect on granular materials is smaller than on cohesive materials because granular material behavior depends more on frictional properties [1]. Some laboratory tests showed that a high frequency of repetitive load results in lower permanent deformation in granular material [2]. In another study, Korkiala-Tanttu studied the effect of loading speed on the permanent deformation of pavement. FE analysis results show that the permanent deformation of unbound material modeled with Mohr-Coulomb decreases by about %25 by the decreasing loading speed from 80 km/h to 12 km/h at 25 Co. The same tendency obtains in this study in laboratory tests [1].
The loading speed also affects the elastic surface deflection of flexible pavement. Full-scale loading tests on instrumented flexible pavement show that increases in vehicle speed result in a decrease in surface elastic deflection [3]. Mshali and Steyn's study also shows that Granular Base/Subbase pavements are less sensitive to the speed change when compared to bitumen treated base or cemented base [3].
Lu et al. [4] studied the dynamic response of pavement-subgrade-soft ground systems subjected to moving load. Numerical results show a decrease in displacement as load frequency increases. Lu and Yao [5] also studied pavement vibration due to road traffic. Two peak points are obtained in the displacement versus vehicle speed curve. Two critical speeds corresponding to the natural frequency of coupling of the vehicle pavement system are observed [4]
This study aims to evaluate the effect of vehicle speed frequency on the deformation behavior of a flexible pavement system. Response of pavement-subgrade system is determined with finite element method by using Plaxis software. Permanent deformation is only considered in this study.

2 Material and model

The number of flexible pavement layers and their thickness depends on the material used in layers, subgrade material strength parameter, groundwater table, climate conditions, road serviceability life, traffic load condition, etc.
The physical model of the analyzed cross-section of pavement-subgrade is a multi-layered system. The top layer is asphalt concrete. Steel slag was selected as a base and subbase material because of having a better performance compared with natural aggregate and also for the sustainability of construction materials [6]. The layered pavement rests on a clay subgrade layer (Figure 1).

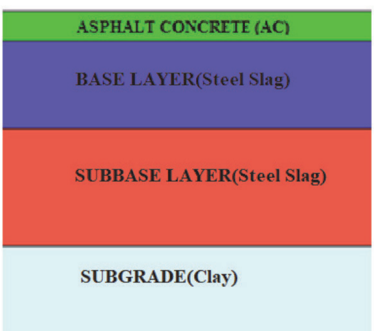

Figure 1 Flexible Pavement cross-section [7]

Asphalt concrete (AC) is 10 cm in height. Unbound granular base and subbase layers have a thickness of 30 cm and 40 cm, respectively. This superstructure rests on a clay subgrade.
For neglecting boundary conditions, finite element model sizes should be selected in appropriate dimensions [8-12]. The numerical model size is 30 m in height and 30 m in width.

These sizes are about 100 times of loading diameter in both directions. Plaxis standard fixity boundary condition was selected. The base of geometry is fixed in each direction. However, deformations of the “y” direction at two vertical edges are free (Figure 2).

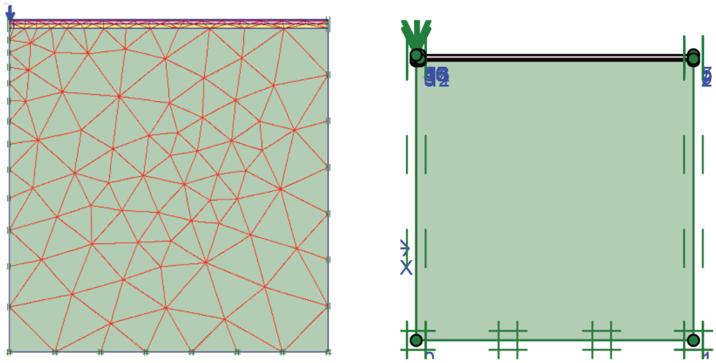

Figure 2 General view of the finite element model

All analyses were performed under 400 kPa triangular repetitive traffic load, using 2D axial symmetric analysis. For pavement response to loading frequency, analyses were performed under different loading speeds (Table 1). Wheel contact areas were assumed to be square areas with a side length of 300 mm.

Table 1 Loading speeds

km/h	10	20	30	45	60	90	120	140	160
m/s	2,8	5,6	8,3	12,5	16,7	25,0	33,3	38,9	44,4

Steel slag deformation parameters were obtained by performing resonant column tests [6]. Shear strength parameters were taken from the literature [13]. The HSsmall soil model was used for representing the granular base, subbase layers and clay subgrade layer. Asphalt concrete was modelled with Mohr-Coulomb (MC) material model. Soil constitutive models and material parameters are shown in Table 2.

Table 2 Material parameters

Properties	Asphalt Concrete (AC)	Steel slag base	Steel slag subbase	clay Subgrade
Model	MC	HSsmall	HSsmall	HSsmall
Thickness (m)	0.1	0.30	0.40	30
Go^{ref} (MPa)	-	180	138	55
$E50^{ref}$ (MPa)		160	124	24
E^{ref} (MPa)	4500			
v (Poisson ratio)	0.30	0.35	0.35	0.20
C (kN/m2)	500	47	45	100
φ (Friction angle) (°)	46	47	45	10
Rayleigh damping		5 %	5 %	5 %

3 Results

Analyses were performed under 400 kPa pulse load for different loading cycles and separated loading speeds. Deformation graphs have two main characteristics. The deformation is increasing with increasing pulse numbers. The pulse number represents the number of cyclic loads applied to the pavement surface. The other important point is that vertical deformation curves have two local maximum points. According to the graph, two critical loading speeds corresponding to the two natural frequencies of the system are obtained (Figure 3).

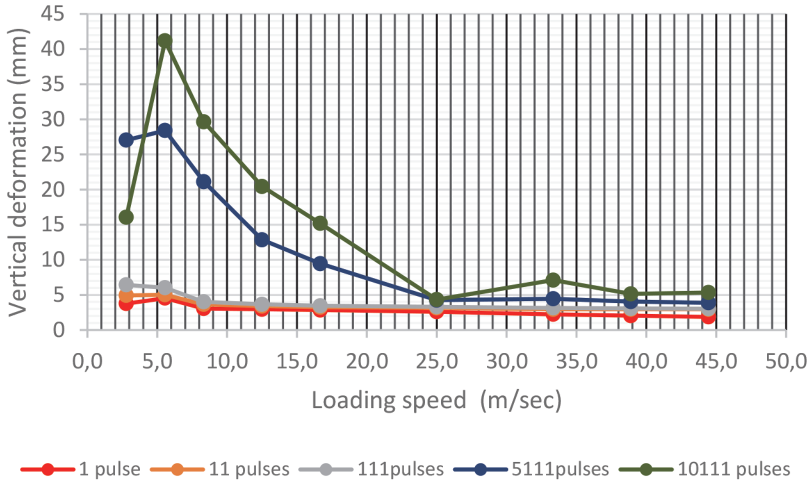

Figure 3 Vertical deformations versus loading speed

According to deformation curves, the deformation increase in the first critical speed is much higher than the second critical loading speed deformation (Fig. 3). The increase in vertical deformation at the critical speeds is clearer when load cycles are higher. The results of analyses also show that total vertical deformation for the analyzed section has a minimum value for 90 km/h loading Speed (6.94 Hz). Total vertical deformation of the cross-section increases on both sides of this point with increasing or decreasing the loading speed. These results are consistent with previous studies. Results show us that for certain road cross-sections, controlling the loading speed will lengthen the road serviceability life by reducing the deformation.

4 Conclusions

Traffic loads are one of the main factors causing permanent deformation in pavements. Besides the load level, loading frequency effects on the structure is a well-known phenomenon in the dynamic analysis of structures. This study focuses on the loading speed effect of repetitive traffic loads on flexible pavements. The finite element analysis method was used to understand flexible pavement response according to loading speed by carrying out a 2D axial symmetric analysis. Unbound material and clay subgrade material behavior were represented with the HSsamll soil material model. Asphalt concrete was modeled with the MC material model. Analyses were carried out for nine loading speeds under 400 kPa triangle pulse load. Results show that deformation curves have two main characteristics: First, the deformation increases with increasing load cycles. Secondly, vertical deformation curves of flexible pavements have two local maximum points corresponding to the natural frequency of layered flexible pavement.

The first critical loading speed is about 5.5 m/s, and the second critical loading speed obtains about 33.5 m/s. However, the deformation increase in the first critical speed is much higher than the second critical loading speed deformation. The increase in vertical deformation at the critical speeds is clearer when load cycles get higher. As stated above, critical loading speeds point out the natural frequencies of the layered pavement system. Deformations get higher when the loading speed is close to the system's natural frequencies. The results of analyses also show that total vertical deformation for the analyzed section has a minimum value for 90 km/h loading Speed (6.94 Hz). Total vertical deformation of the cross-section increases on both sides of this point with increasing or decreasing the loading speed. When summarized, controlling the loading speed for particular road cross-sections will lengthen the road serviceability life by reducing the deformation.

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